3.6 An Organic Imager for Flexible Large Area Electronics

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Interest in organic semiconductor technologies is sustained in part by the promise of large area and flexible electronics. Early work has focused on the fabrication and characterization of discrete devices such as a single organic field effect transistor (OFET) or organic photodetector (OPD). Creating an addressable imaging system, however, requires an integrated approach for both device fabrication and testing. This work demonstrates a near room temperature (<95˚C) process flow capable of fabricating integrated OFETs and OPDs, by using a combination of photolithography and inkjet printing techniques, both suitable for use on mechanically flexible substrates. A proof-of-concept active-matrix imager, consisting of OFET switches with OPDs, two metal layers, and patterned lateral photodetectors, is fabricated and tested. Measurements indicate an OPD responsivity of $6x10^{-5}$A/W and an on/off ratio of up to 880.

On top of a glass substrate, a lithographically patterned pentacene OFET backplane is first fabricated in the form of an addressable array for selecting individual photodetector elements, following the lithographic process described in [1]. After the OFETs are defined, they are passivated with a 200nm layer of parylene (an organic CVD deposited insulator). In order to expose the photodetector electrodes after passivation, the parylene is patterned using photolithography and dry etching. This creates vias to the source/drain metal layer where the OPD electrodes are defined. A colloidal dispersion of photosensitive titanium(IV) oxide phthalocyanine (TiOPC) solvated in butyl acetate (obtained from H.W. Sands) is then drop-cast onto the exposed electrodes using a thermal inkjetting dispenser with a nominal drop size of 220pL. This inkjet approach patterns the TiOPC photoconductor islands. The number of drops in the ink-jetting sequence, drying time between drops, and TiOPC solution concentration were optimized for maximum photoresponse. Unlike previous organic imagers [2, 3], this scalable process patterns all devices on a single substrate and incorporates printed organic elements. Figure 3.6.1 illustrates a layer cross-section of the fabricated devices.

The circuit schematic of the integrated 4×4 imaging array is shown in Fig. 3.6.2. Each pixel contains an OFET with W/L of 1000μm /5μm, and a lateral, serpentine photodetector with effective width of approximately 25mm and finger separation of 5μm. The photodetector in the on state was designed to have a conductance two orders of magnitude less than the on-conductance of the OFET switch. This allows the photodetector to dictate the photocurrent when the OFET is biased on. The pixel has dimensions of $700\times700\mu m^2$ and uses a 25V power supply. The 4×4 imaging array occupies an area of $10.24mm^2$. The pixel was characterized by illuminating it at varying intensities with a 530nm wavelength LED (Lumileds), while the pixel's pass transistor was biased on (i.e. PD Select 1=0V). The current flowing through this branch was sensed at PD Out 1 while all other PD Select lines were biased at 25V (i.e. all other rows were turned off). Figure 3.6.3 plots the pixel conductance vs. light intensity. Measurements confirm a pixel responsivity of $6x10^{-5}$A/W and a maximum on/off ratio of 880.

The active-matrix system was tested by first placing it under flood uniform illumination from the LED. Pixel currents were measured at PD Out 1 through PD Out 4 by a HP 4156 parametric analyzer, while the PD Select line biases were rastered to obtain every pixel's response. Figure 3.6.4 shows the conductances measured from each pixel under uniform flood illumination. Since the OPD's conductance is two orders of magnitude less than the OFET's, we believe the OPD accounts for much of the variance in pixel conductance. Our current inkjetting process results in observable process variation since each pixel's fingers are partially covered with photosensitive material with varying thickness. The measured variation in photoconductance at each pixel is recorded for subsequent calibration.

Next, a transparency mask in the shape of a "T" was placed in the field of the LED, producing a shadowed "T" region on the imager. Figure 3.6.6 shows the imager under test. Column 2 of the imager was completely covered by the "T" shadow, and column 3 only partially. To calibrate for pixel conductance variation, the conductances recorded from the patterned test were divided by the conductances under flood illumination resulting in a ratio for each pixel. This method approximates the pixel conductance versus luminance curve as linear. Figure 3.6.5 plots the ratio of sensed conductance to calibration conductance for each pixel while shining a shadowed "T" shape on the imager. The imager correctly produces a lower ratio for column 2 than column 3, since 2 is completely shadowed and 3 only partially.

A 4x4 imager has been fabricated using an at near room temperature (<95˚C) process, ensuring that the integrated fabrication process is suitable for flexible plastic substrates. The individual pixels of the imager were measured to have an on/off ratio of up to 880 and average responsivity of 6×10^{-5}A/W. Process variation in the inkjetted material is accounted for by first calibrating the imager under flood illumination. The active-matrix system is demonstrated by successfully imaging a "T" pattern.

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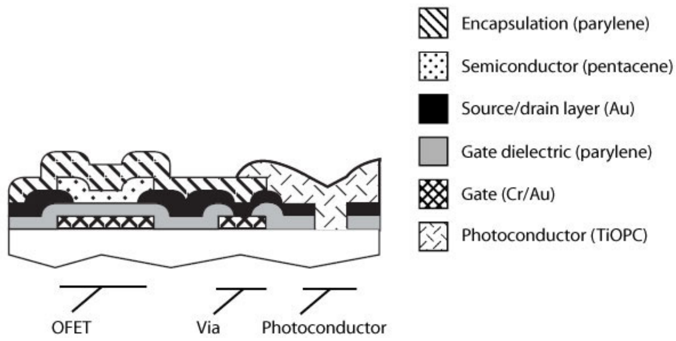

Figure 3.6.1: Layer cross-section of the integrated organic devices.

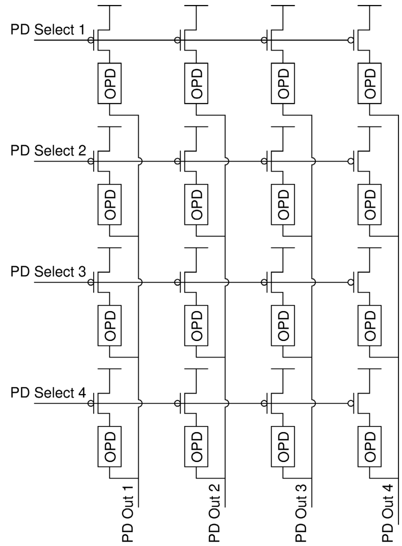

Figure 3.6.2: Circuit schematic of the 4×4 organic imager.

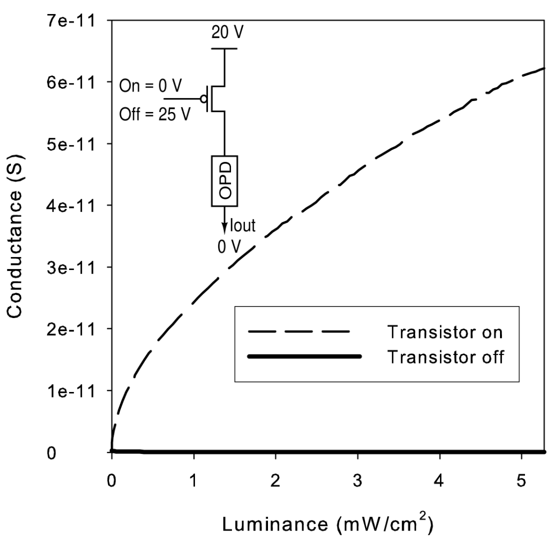

Figure 3.6.3: Conductance vs. luminance for an individual pixel. The transistor conductance biased at V_{SG}=20V is 20nS.

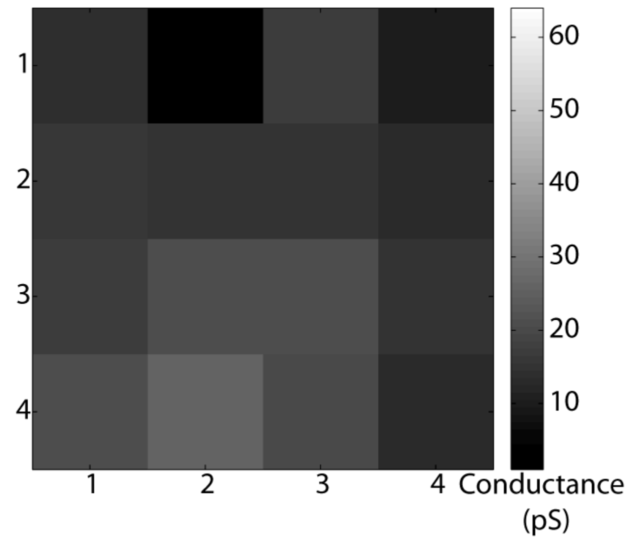

Figure 3.6.4: Imager response under flood exposure to capture variation in the pixel response.

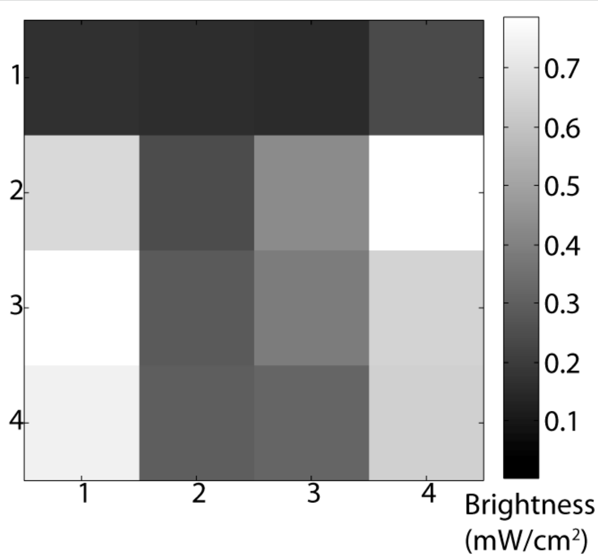

Figure 3.6.5: Imager response under "T" shadow pattern after calibration.

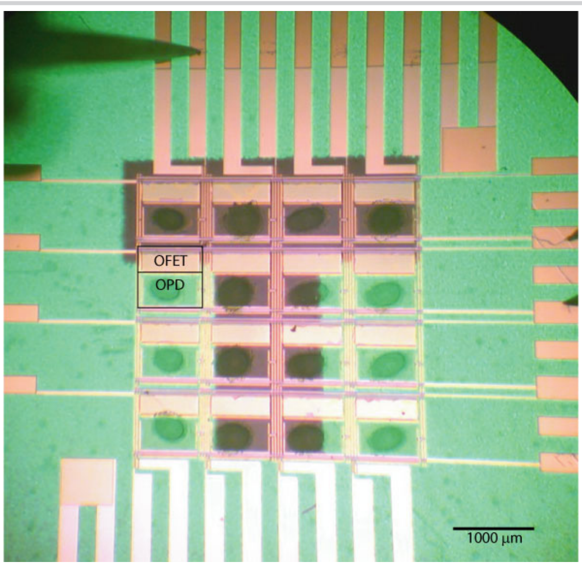

Figure 3.6.6: Micrograph of imaging array under test.